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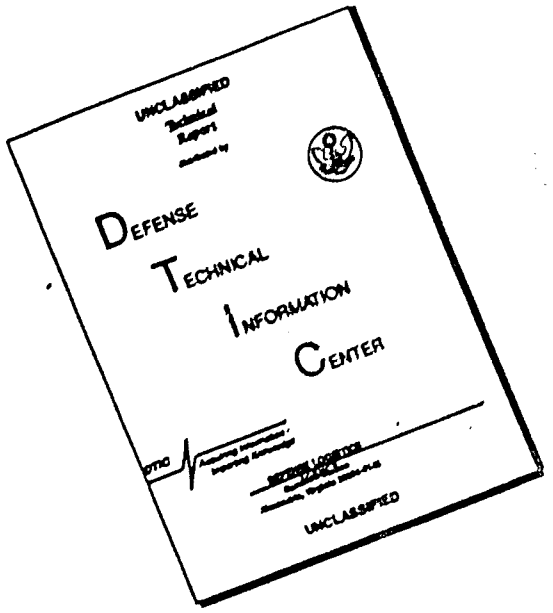

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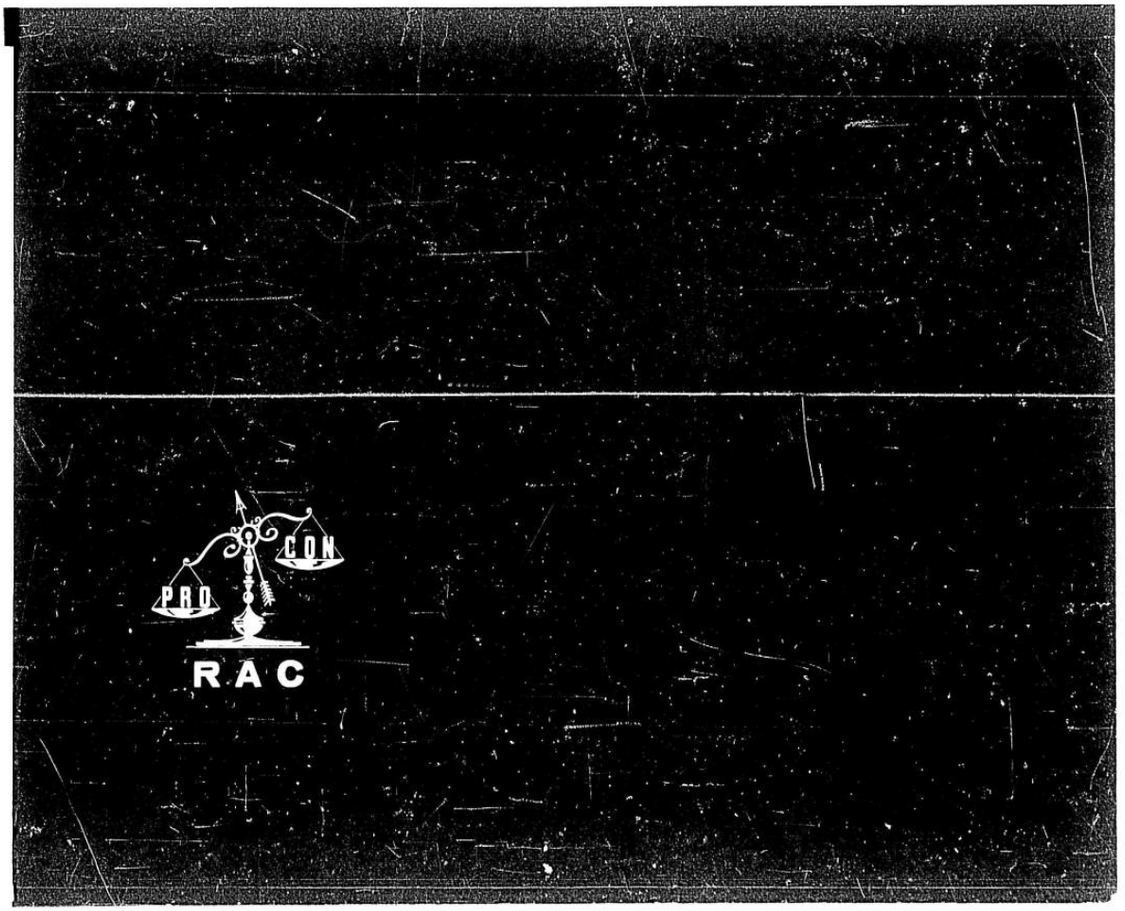
RESEARCH ANALYSIS CORPORATION

A Look at US Army Operations Research-Past and Present



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COMBAT SYSTEMS
TECHNICAL PAPER RAC-TP-102
Published April 1964

A Look at US Army Operations Research-Past and Present

by
Lynn H. Rumbaugh

RESEARCH ANALYSIS CORPORATION
McLEAN, VIRGINIA

FOREWORD

The paper published herewith was presented at the Eighth ABCA Discussions on Army Operational Research, held at the Industrial College of the Armed Forces, Ft Lesley J. McNair, Washington, D.C., 17–28 June 1963. It is included in the list of titles below representing RAC papers that were prepared originally for the Eighth Quadripartite.

Lynn H. Rumbaugh, "Critical Appraisal Address, United States," RAC-TP-102. UNCLASSIFIED

Nicholas M. Smith, "Technological Forecast in the Techniques of Operations Research," RAC-TP-103. UNCLASSIFIED

Philip H. Lowry, "Dual Capability in a Theater of Operations (U)," RAC-TP-104. SECRET

C. A. Warner, "Southeast Asian Conflict and Operations Research (U)," RAC-TP-105. CONFIDENTIAL

Irving H. Siegel, "Allocation of Resources: Problems of Strategic Posture and Readiness," RAC-TP-106. UNCLASSIFIED

H. N. Hoppes, "Promoting Combat Developments through Mathematical Models," RAC-TP-107. UNCLASSIFIED

Anthony V. Fiacco and Garth P. McCormick, "Algorithm for Nonlinear Programming: Resource-Allocation Methodology," RAC-TP-108. UNCLASSIFIED

James W. Johnson and Richard E. Zimmerman, "A Quick-Gaming Calculation of Seventh Army Defensive Operations (U)," RAC-TP-109. CONFIDENTIAL

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A Look at US Army Operations Research-Past and Present

ABBREVIATIONS

AORG	Army Operational Research Group
ARO	Army Research Office
CORG	Combat Operations Research Group
HUMRRO	Human Resources Research Office
OCRD	Office, Chief of Research and Development
OR	operations research
ORO	Operations Research Office
OSRD	Office of Scientific Research and Development
SORO	Special Operations Research Office
WSEG	Weapons Systems Evaluation Group

SALUTATION

The Office of the Chief of Research and Development (OCRD) of the US Army has honored the Research Analysis Corporation (RAC), of which I am a staff member, by asking us to join with the Army Research Office (ARO) as co-hosts to the Eighth ABC Discussions on Army Operational Research. I join the previous speakers in bidding you welcome.

We may recall with some pride and considerable gratification that the Tripartite Agreement among the US, British, and Canadian armies on operational research was the first of all the now numerous Tripartite agreements on standardization and data exchange. These agreements now are being extended to Australia as the fourth member of a Quadripartite.

The First Tripartite Conference on Army Operational Research was held in London, 21–30 April 1949, less than a year after the Operations Research Office (ORO), predecessor to RAC, was established in July 1948 to begin the US Army's first organized studies in operations research (OR).

At that time Britain's Army Operational Research Group (AORG) already was in its ninth year. Needless to say, we leaned heavily on British Army operational research experience in those earlier days. In fact we still do. For example, within the past year RAC has reprinted, with British permission, some 1000 pages of AORG papers and studies on guerrilla warfare and counterinsurgency operations.

This eighth international meeting coincides with the 15th anniversary of OR in the US Army. On this occasion the Organizing Committee has asked that in addition to the three major topics the Delegates and Observers should address themselves to establishing benchmarks for Army operational research in the hope and expectation that this eighth meeting may reach some broad, general conclusions to guide and assist us and our respective Armies in better utilizing our professional skills.

In addressing the task set by the Organizing Committee, my allocated time will not permit more than a broad-brush treatment. I will not attempt to be inclusive or definitive, but I can try to be somewhat provocative. I expect—indeed, I hope—that you will not agree to all I am about to say. This is a good spot to make the standard disclaimer: "The opinions I am about to express are my own, and do not necessarily represent those of the US Army or any of its agencies."

May I suggest three questions about Army operational research?

Where have we been?

How did we get where we are now?

Where do we appear to be headed?

OPERATIONAL RESEARCH IN WWII

Occasional use of techniques resembling OR trace back to antiquity. I like to cite Archimedes at the siege of Syracuse (215–212 BC), although it has been pointed out to me that this is scarcely consistent with my view that OR is team research. Incidentally, a recent OR bibliography[1] abstracts an article by Niccolò Machiavelli (a one-time defense secretary of the Florentine Republic), published posthumously in Rome in 1531 under the title, "What Dangers Are Run by One Who Takes the Lead in Advising Some Course of Action."

It is generally recognized that OR as we know it today had its beginning in the British military services just prior to and in the early stages of WWII. The British invented it and named it "Operational Research." News of its numerous successes soon crossed the Atlantic.

When the United States entered WWII, first the US Navy and then the "Army Air Force" adopted OR from the British experience. The first sizable group, the Anti-Submarine Warfare Operations Research Group, was established in May 1942 in the Office of the Chief of Naval Operations under the auspices of the wartime civilian Office of Scientific Researoh and Development (OSRD) with Dr. Philip Morse as Director. Even earlier, in the fall of 1941 just before we entered the war, a small informal group was started by Dr. Ellis A. Johnson at the Naval Ordnance Laboratory, with encouragement from visiting British scientists, to study mine-warfare and countermeasure operations. So far as I know the first formal US publication in military OR was on the contest between mine sweepers and mine layers.

What kinds of training and experience were used in these early days? There were physicists, engineers, mathematicians. Professor Blackett, himself a physicist, is said to have started operational research in all three British services. Nevertheless natural scientists were quite prominent among the early contributors to British Army Operational Research; one could speculate that the biological scientist, with his training in making measurements and observations amongst a clutter of uncontrolled variables, is quickly adaptable to military OR!

In the US Navy the larger part of OR was carried out by physical scientists and mathematicians.

In the Air Force Dr. Lauriston Taylor, a physicist from the US Bureau of Standards, headed a group attached to the US Ninth Air Force in Europe. Most of this group were physicists, including Dr. Nicholas M. Smith of the RAC Staff who will present a paper on methods and techniques in OR later at this meeting.

However, the first civilian Air Force OR group to be formed was headed by a lawyer—John Marshall Harlan, since 1955 an Associate Justice of the US Supreme Court. I have heard two explanations of this assignment: (a) The legal profession, with its training in gathering, sifting, and evaluating fragmentary and frequently contradictory evidence, surely must have special talents for military OR; (b) when Professor P. M. S. Blackett was queried about British experience, he said the British had tried practically every profession except corporation lawyers; this remark was misunderstood as a recommendation, and his hearers set out to enlist a prominent lawyer to head their first group.

In either case it worked out quite well, and you can take your choice of explanations.

All of the groups I have mentioned were formally organized and officially assigned to perform OR. In addition the wholesale enlistment of British, Canadian, and American civilian scientists in the war effort naturally and inevitably led to many unofficial or accidental ventures into OR. For example, just 21 years ago, in June 1942, I was busy analyzing the raid on Sydney Harbor by four Japanese miniature (80-ft) submarines, not the job I had been sent to Australia to do.

For my first benchmark I will summarize military OR experience in WWII in five points as follows:

(1) The US principally used physical scientists, engineers, and mathematicians, but the British found that biological scientists were comparably skilled and adaptable for military OR.

(2) Despite many successes, OR during WWII was largely confined to comparatively elementary analyses of action problems involving aircraft, ships, submarines, and simple weapons systems, i.e., two-element problems having the general characteristics of a duel. Complex interaction problems, such as multielement ground-combat operations, generally were not undertaken.

(3) Most of the data were drawn from operationally ready forces deployed for or engaged in combat.

(4) A majority of the problems solved were of a practical quick-fix nature.

(5) Reports of field work appear not to have been systematically kept or centrally collected for possible future use. Some of the WWII work was forgotten and had to be redone in Korea.

There have been many changes in OR since WWII. Is it possible that all have been for the better? I know some of you do not think so. All right; let this meeting ask its members these questions:

What changes have been good?
Which have been bad, and why?
Are there any important gaps or omissions?

MILITARY OPERATIONS RESEARCH FOLLOWING WWII

When the war ended, civilian engineers soon were back at their peacetime jobs and professors returned to their campuses. However, in both Britain and the US wartime OR groups were continued at reduced strengths after WWII and with some amalgamations and name changes are still active and viable today.

After a short, rather drastic demobilization period, military OR resumed its growth. In the 4-year period before Korea, when US military forces were being steadily reduced, military OR was growing.

In March 1946 Project RAND was started by contract with Douglas Aircraft Company, and in 1948 became the RAND Corporation, a new not-for-profit organization. Its first publication was a radical departure from the quick-fix problems of WWII. The title was "Preliminary Design of an Experimental World-Circling Spaceship."

The National Security Act of 1947 established the Department of Defense and was followed quickly by the formation in the fall of 1947 of the Weapons Systems Evaluation Group (WSEG), as an adjunct of the Joint Chiefs of Staff.

Operations Research in the US Army

OR at Army general staff levels was started in July 1948 by contract with The Johns Hopkins University. The General Research Office was located at Ft Lesley J. McNair in a since-demolished building of the Industrial College of the Armed Forces. The formal announcement was signed by Gen Omar Bradley, now a member of the Board of Trustees of RAC. The organization was renamed Operations Research Office (ORO) in December 1948, but remained under continuing contract with the Department of the Army until September 1961, when contract management passed to RAC, a nonprofit organization chartered to perform research on behalf of the US.

In 1953 ORO had established the Combat Operations Research Group (CORG) at headquarters, Continental Army Command, Ft Monroe, Va., and passed its operation to Technical Operations, Inc., in 1955. In the recent reorganization of the principal Army Commands this group moved to Combat Developments Command Headquarters, Ft Belvoir, Va. CORG applies OR techniques to problems of organization, tactics, and doctrine. Another contract group, now furnished by Stanford Research Institute, in support of the Combat Development Experimentation Center (CDEC) at Ft Ord, Calif., was established in 1956.

Two other contract groups work primarily in the social and behavioral sciences. In 1951 the Human Resources Research Office (HUMRRO), a contract agency administered by The George Washington University, was formed to concentrate on research involving human factors pertaining to the US soldier, his training and environment. In 1957 the Special Operations Research Office (SORO), a contract agency under the American University, was formed to specialize in area cultural studies and the sociological and psychological implications of hot and cold war. These organizations, like RAC, receive most of their work from the General Staff and major Commands, and may be called "Army-wide" research agencies. Collectively the five now have a total of over 400 technical personnel (May 1963) and account for most of the current US Army effort in OR at major Command and General Staff levels.

Mrs. Helen Milton of RAC has collected information on other Army contractors and in-house groups that use OR techniques for special studies or areas of study.

In FY62, according to information furnished to ARO, 20 different study contractors and 50 research studies of this special nature were sponsored from 11 Army agencies in support of their in-house activities. The contractors included universities and private organizations, large and small. Studies ranged across the board from automatic data processing to field-army medical-support systems and antimissile missiles.

The remaining Army OR effort is divided among at least 20 in-house groups scattered among nine Army Commands and agencies, having about 200 civilian and military personnel and ranging in size from 2 to 40 professionals. Like the 20 study contractors, these 20 in-house groups work mostly in specified study areas within the missions of the Army agencies to which they are attached.

Operations Research Personnel

These changes in the structure and nature of the OR community have generated concomitant changes in personnel. In the US nearly all the pioneer work in OR was done by mathematicians and physical scientists. From the start ORO departed from WWII practice, and by 1953 over 40 percent of its staff were from economics and human arts and sciences. Today their combined fraction at RAC is still 40 percent of our staff, but the number of economists has gone up markedly while the humanists have declined sharply in percentage though not in total numbers. A considerable increase in the percentage of mathematicians and statisticians has been matched by a marked decrease in the percentage of engineers and physical scientists, and the number of natural scientists has remained small (see Table 1).

In 1953 ORO performed nearly all the OR for the US Army. If we include the other four junior Army contractors, the outstanding change during the past 10 years has been the great increase in behavioral scientists. The ratio of engineers and physical and natural scientists to behavioral scientists once was 4 to 3. It now is 2 to 5. The nature of each contractor's work is strongly reflected in the kind of personnel employed. In 1963 over 90 percent of the economists were at RAC, 80 percent of the psychologists at HUMRRO, and two-thirds of the political scientists at SORO.

It is interesting to note that only one organization has reported a substantial number of operations analysts, presumably on the grounds of on-the-job experience. To my knowledge the number of OR professors who are alumni of Army OR exceeds the number of persons with OR degrees working for the Army at present.

Trend in Army Operations Research Programs

In looking back for changes in Army OR I have had available a summary of semiannual reports,[2] referencing about two-thirds of the ORO reports and papers sent to the Department of the Army over a period of years.

In the search for trends I undertook to break this summary down into the 14 topics shown in Table 2 (plus the inevitable "Miscellaneous" of an incomplete taxonomy).

There was no evidence of any really large changes in study topics over a period of 13 years. The principal trends were (a) a gradual decrease from 47 to 39 percent in publications on combat operations; (b) a corresponding increase from 21 to 29 percent in publications on logistics and costs; and (c) a modest increase from 2 to 7 percent in publications on methodology.

The decrease in publications on troop training and psychological warfare is due, of course, to the entry of HUMRRO and SORO into these fields.

It often is said that OR is team research in which contributions from several branches of knowledge are combined. If this was always true, we should expect our reports to be composites in which the ratio of topics to subjects would be significantly greater than unity. For example, a report under the subject "Tactical Nuclear Weapons" might include such topics as weapons family, organization and tactics, combat equipment, costs, effects on logistic operations, and political implications, giving a topic/subject ratio of 6/1.

TABLE 1

Distribution of OR Personnel by Original Disciplines

Subject	ORO-RAC		Five Army contractors[a]
	1953[b]	1963[c]	1963[d]
	Percent		
Formal			
Mathematics and Statistics	8.1	19.0	14.1
Philosophy	1.8	1.8	0.7
Subtotal	9.9	20.8	14.8
Predictive			
Engineering	19.8	16.1	10.2
Physics	16.2	11.3	5.3
Chemistry	4.5	4.1	1.7
Earth Sciences	2.7	4.1	1.7
Subtotal	43.2	35.6	18.9
Biology	0.9	1.2	0.5
Physiology	1.8	0.6	0.7
Botany	0.9	1.2	0.7
Subtotal	3.6	3.0	1.9
Prescriptive			
Economics	7.2	13.7	6.1
Business	—	3.6	2.7
Subtotal	7.2	17.3	8.8
Psychology	8.1	3.0	29.7
Political Science	9.9	7.1	8.8
History	9.9	6.0	4.1
Military Science	1.8	4.2	2.9
Anthropology	0.9	—	2.0
Sociology	1.8	1.2	2.0
Literature, Language, and Law	3.6	1.8	3.9
Subtotal	36.0	23.3	53.4
Operations Analyst			2.2

[a]RAC, HUMRRO, SORO, CORG, CDEC.
[b]Total personnel, 111.
[c]Total personnel, 169.
[d]Total personnel, 411.

TABLE 2

Percentage Distribution of Topics in ORO Semiannual Reports July 1948–June 1961, by Subject

Study topic	Jul 48–Jun 51[a]	Jul 51–Jun 54[b]	Jul 54–Jun 58[c]	Jul 58–Jun 61[d]	Weighted 13-yr avg[e]
	Percent				
Combat Operations Requirements					
Troop strengths, organization, doctrine, and tactics	7	10	15	11	12
Weapons and effects	25	18	19	18	19
Combat equipment and vehicles	11	7	8	6	8
Intelligence interpretation and theory of procedure	4	6	3	4	4
	47	41	45	39	43
Logistics and Costs					
Logistics operations	9	3	6	8	6
Support logistics	6	5	6	10	7
Production and costs	6	9	12	11	10
	21	17	24	29	23
Combat and support, total	68	58	69	68	66
Background Studies					
Social, cultural, civil affairs environment	4	7	3	3	4
International, (strategic, economic, and political)	8	4	3	7	5
	12	11	6	10	9
General Studies					
Selection, training, and performance	7	9	3	2	5
Psychological warfare	7	8	4	—	5
Special warfare and counterinsurgency	—	4	3	1	2
	14	21	10	3	12
Special Studies					
R&D management	4	2	6	8	5
Methodology	2	3	5	7	5
Miscellaneous	—	5	4	4	3
	6	10	15	19	13

[a]Ratio of total topics to subjects 1.33.
[b]Ratio of total topics to subjects 1.18.
[c]Ratio of total topics to subjects 1.50.
[d]Ratio of total topics to subjects 1.27.
[e]Ratio of total topics to subjects 1.32.

The more surprising feature of Table 2 is that the ratio of topics to subjects is so small. The practice of publishing and releasing parts of composite studies as they were finished, instead of in completed packages, accounts for part of this, but the fact remains that over the years a large portion of the subjects treated were narrow, single-topic studies and that integrations and syntheses were comparatively rare.

This is shown rather strikingly in Fig. 1, where the topic/subject ratio is plotted as a function of semiannual reporting periods. This graph shows a remarkable periodicity in which each crest and trough has a specific explanation.

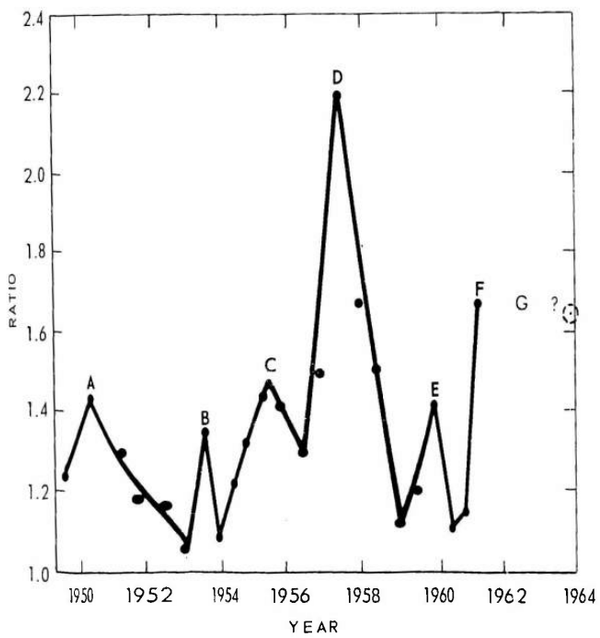

Fig. 1—Index of Compositeness: Topic/Subject Ratios by Half Years

Thus peak B resulted from project teams working on cost-effectiveness studies which compared single-purpose weapons systems, e.g., a comparison of cannon, rockets, guided missiles, aircraft, and drones in the bombardment of fixed ground targets. Peak F resulted from a crash study on dual-capability forces.

One of the more significant changes has been that, whereas the earlier peaks resulted from the formation of special project teams to study fairly broad problems in the regular work program, the later peaks are due primarily to the superposition of crash studies on a functional organization normally fully engaged in rather narrow or fractionated problems.

Compositeness is the antithesis of suboptimization. An increase in study compositeness represents a partial escape from the inherent dangers of suboptimization that plague both Army OR and the Army itself. It is questionable that crash studies are the better way to accomplish this. As Dr. Koopman

pointed out at the conclusion of a speech by Charles Hitch at the Vicennial Conference of the Operations Evaluation Group, preoccupation with a series of epidemics can result in neglecting the basic medical research required to cope with future epidemics.

This leads to three fundamental questions in the management and assignment of Army OR studies:

What is a reasonable balance between composite and single-purpose studies?

How can this balance best be achieved?

Is there some optimum compromise between a functional and a project type of organization for military OR?

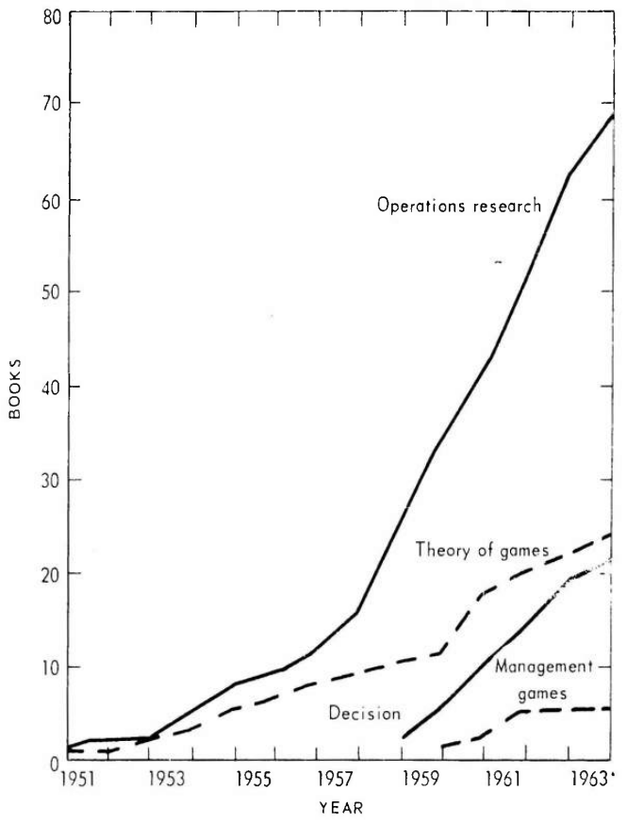

Fig. 2—Accumulation of Books, 117 Titles
*Includes announcements.

OPERATIONS RESEARCH LITERATURE

Naturally most of the early unclassified literature in OR reflected its military origin and concentration on comparatively simple problems. In 1951 there were only three books—two on OR itself and one on the theory of games. Today there are 117 books on OR (see Fig. 2) and closely related fields, with

little evidence yet of saturation. Many of the newer titles are designed to appeal to business and industrial management.

Present-day books and journal articles on techniques are rather numerous. But except for studies in the general interest, such as hospital management and traffic problems, articles on actual OR applications are rather sparse, probably because military OR cases are usually classified and industrial applications are proprietary to the client.

GROWTH IN OPERATIONS RESEARCH TECHNIQUES AND METHODOLOGY

Today, then, the increase in OR tools and techniques has enabled us to tackle increasingly complex problems, but much of the increase has been in the solution of management problems. We still have a long way to go in developing techniques for military problems, such as combat effectiveness, which has no civilian counterpart. I will not say much about such techniques as war gaming—an ad hoc group is reporting on that—or about future techniques, since Dr. Nicholas M. Smith has a separate paper on a technological forecast of OR techniques.

The majority of the techniques used in WWII were summed up in a concise 150-page volume by Morse and Kimball.[3] By 1956 Russell Ackoff in a JORSA article[4] identified nine types of OR problems (organization, decision, inventory, allocation, waiting-line, routing, replacement, information collection, and competitive), and listed 153 references on techniques for solving them. When a new technique appears in the journals, a rapid flow of similar articles may be generated or released. Thus in April 1962 Clifford Bigelow[5] listed a bibliography of 52 articles on project planning and control by network analysis that had been published under a variety of titles in less than three years after the first articles on the Navy's use of program evaluation and review technique appeared in April 1959 in the open literature.

Despite these rapid advances in OR for management, some of the oldest problems remain among the most troublesome. Thus there is no general solution to the cost-effectiveness problem of equipment maintenance and replacement as it obsolesces or fails. In fact even the expression for expected failures as a function of time cannot be evaluated analytically for a policy of group replacement, supplemented by interim replacements of failures when they occur.

This kind of problem is especially acute for first-line Army equipments where the penalties for failures during combat missions are likely to be severe.

The layman does not always appreciate this. A year or so ago a Congressman asked why the Army was spending so much money on scientists to study vehicle maintenance. If he had had the problem, he would have consulted a good garage mechanic, or at most the operator of a fleet of trucks.

EXCHANGE OF INFORMATION ON MILITARY OPERATIONS RESEARCH

It would seem only reasonable for the military operations analyst to make the most of the classified literature he has, without waiting for it to be declassified and published in the open literature.

One would suppose that the military operations analyst has an advantage over his industrial and academic colleagues since in principle he has access on a need-to-know basis to an additional and large accumulation of classified literature. Most of us have heard complaints that classified papers are not circulated as freely as they should be among and within the military services. How serious this really is, I do not know; I do know that an information block can be extremely frustrating.

To start with there is no classified equivalent of the "Letters to the Editor" section, found in many professional journals, where new developments and discoveries are announced, failures to quote pertinent references are exposed, and errors are remarked or corrected.

Furthermore there is no classified military periodical corresponding to "International Abstracts in Operations Research," which is published by the International Federation of Operational Research Societies and attempts to cover all published articles and books bearing on OR, regardless of professional source or nation of origin.

On the surface it would appear that classified "Letters" and "Abstracts" could serve similar purposes without going into enough detail to tear any large holes in the "need-to-know" screen.

This leads to a two-part question:

(a) Is the present Data Exchange Agreement sufficient, or should it be supplemented by a classified "Military OR News and Abstracts" type of periodical?

(b) If needed, would such a periodical be practicable from the viewpoint of cost, effort, and security restrictions?

TECHNIQUES AND TOOLS FOR ARMY OPERATIONS RESEARCH AND SOME OF THEIR LIMITATIONS

In WWII and Korea, an operations analyst could take off on a data hunt and complete his report in the theater, armed with nothing more bulky than a good supply of practical judgment, plus perhaps a slide rule, a handbook of physical constants, or a few tables of distribution functions.

Many OR problems may still be solved with these simpler tools, and a large slice of our current work is on problems of this nature.

The primary new tool in OR is of course the electronic computer. It has enabled us to plunge into areas, e.g., data processing, linear and nonlinear programming, simulation, and operational gaming, on a scale where sheer size and complexity would have swamped us several years back—and could swamp us in the future.

Despite the power of modern computers it is easy to pose combinatorial problems that lie far beyond the brute-force capabilities of any present or conceivable future computer. W. Ross Ashby has pointed out that there are around 10^{40} possible moves in a chess game, and that simple but detailed simulations of, say, every element in a brigade can involve over 10^{100} possible permutations and combinations.

Dr. Nicholas M. Smith has called this the "number barrier." The practical barrier in OR is a fivefold composite of number, time, cost, utility, and potential (for contributing to the state of the art).

If one includes computer time, model building, programming, and analyses of output, he can estimate rough limits for the sizes of problems he profitably might undertake with computer-assisted simulations. Assuming he will not exceed his distributed share of the US Army's RDTE budget, this turns out to be about 10^{10} elementary calculations per $1-million decision affected through use of a modern high-speed computer.

This clearly is far too small a number to permit brute-force applications of computers to military simulations and war gaming.

Since military OR analysts cannot expect universities and industry to solve these problems for us, we surely require more research in (a) military applications of computer science; (b) principles of simulation and gaming in order to bring or keep them within manageable ranges of complexity; and (c) application of mathematics to military OR techniques, especially those that may facilitate the extension of specific solutions or simulations to the evaluation of a larger range of alternative courses of action. This is fundamental to many military resource allocation problems.

HIATUS IN MILITARY COST-EFFECTIVENESS PROBLEM SOLVING

Peacetime emphasis in military OR has been increasingly directed toward cost-effectiveness problems. The solutions are basic to decisions on the allocations of budgets for research, development, production, and maintenance of all military weapons and equipments; the status of the mobilization base; and the structure, training, and deployment of forces in being.

In industry, cost and effectiveness frequently are separable or reducible to a common measure of value, permitting analytical solutions or at worst, resort to ad hoc algorithms. This is rarely possible in military cost-effectiveness studies, since values may be expressed in intangibles ranging from human life to national objectives. Weapon mixes and choices of tactics further complicate the Army problem. Human factors and environments also must be included in any overall solution. My definition of OR includes human beings, singly and in groups, as parts of the operational complex to be studied; "Operations research is the study of interactions between men and things, operating in concert or conflict; it encompasses present and future competitive systems in complex fluctuating environments."

This should focus attention on a critical gap in the methodology of OR. We have no adequate theory of value to synthesize the findings of the mathematical sciences, economics, and behavioral sciences in terms of some common measure of merit such as military worth. Consequently most of our solutions are suboptimizations which cannot be inserted directly into a generalized cost-effectiveness equation or a large-scale resource allocation problem.

For example, a quantitative model builder may connect economics with mathematical science and come out with a suboptimal solution in terms of physical constants, such as dollars expended per target destroyed. The logical incompleteness of such physical solutions is obvious. If inserted directly in a cost-effectiveness equation without modification by concepts of military worth they would lead to absurdities such as the elimination of rifles in favor of howitzers or the complete replacement of conventional explosives by nuclear warheads.

On the other hand the behavioral scientist is more likely to give his solution in terms of military value, e.g., in making recommendations for the training and assignment of personnel. But his solutions frequently will be expressed in qualitative terms not easily used by the quantitative model builder.

The conclusion is inescapable. Military OR has much to do before it can give more than suboptimal advice to the decision maker in cost-effectiveness and resource allocation.

In my opinion, an ivory-tower approach cannot get us out of this difficulty. Hard, intelligent work in home offices will not be sufficient by itself.

I urge a return toward the empiricism of former years.

This means more field work—participation in maneuvers, field experiments, and work with the ready forces wherever they may be located.

MAJOR FEATURES OF CURRENT US ARMY OPERATIONS RESEARCH PROGRAMS

Let us take a quick look at current US Army OR programs. Table 3 shows the approximate distribution of current effort in US Army OR. I have had access to FY62 descriptions of work by Army study contractors in addition to CORG, CDEC, HUMRRO, and SORO, and have attempted to sort out work in OR from studies and analyses of a less broad nature, as indicated in the two right-hand columns of the table. The column on the percentages of publications a decade ago by RAC's predecessor is included because it represented practically all the Army OR effort of the time and can be used in comparison with present OR effort by all contractors to show trends.

The following major features may be noted from Table 3 or the data used in constructing it, even though some of the data are stale and need updating.

Realism

Ten years ago most of the OR effort was firmly based on actual combat in Korea. After the truce 113 of our staff members and consultants received the Korean Service Medal of the United Nations Command for work in the combat zone. Operations analysts from Britain and Canada had worked alongside us.

Today much of the effort is at the home offices, in simulations, war gaming, and paper studies of systems never used in combat. Much of the data we need is missing or suspect. Our WWII and Korean experiences are running out. Increasing numbers of our analysts have never seen either an older or new army organization in field operations. We require operational laboratories in the field if we are to conduct OR against a background of realism.

Data Deficiency

After 10 years in military research and development and another 13 years in OR, I have learned the hard way—as have many of you—that there can be large differences in the data available from engineering designers, user tests, and actual performance under combat conditions. Except for limited numbers of costly field experiments and exercises, sources of realistic data have virtually disappeared. The new army has nuclear weapons, guided missiles, armored personnel carriers, and a wide variety of other new equipment that together with

TABLE 3

Percentage Distribution of US Army OR Effort by Subject and Study Topic

Study topic	Army OR contracts			
	RAC only		All contracts	
	1951–1954[a]	1963[b]	OR only, 1962–1963[c]	OR and analyses, 1962–1963[d]
	Percent			
Combat Operations				
Troop strengths, organization, doctrine, and tactics	10	16	18	16
Weapons and effects	18	9	6	8
Combat equipment and vehicles	7	7	4	12
Intelligence interpretation and theory of procedure	6	1	3	3
	41	33	31	39
Logistics and Costs				
Logistic operations	3	16	8	7
Support logistics	5	6	3	5
Production and costs	9	15	6	7
	17	37	17	19
Combat and support, total	58	70	48	58
Background				
Social, cultural, environment	7	1	8	6
International (strategic, economic, and political)	4	8	7	5
	11	9	15	11
General				
Selection, training, and performance	9	—	21	17
Psychological warfare	8	—	3	3
Special warfare and counterinsurgency	4	9	7	6
	21	9	31	26
Special				
R&D management	2	5	2	2
Methodology	3	7	4	3
	5	12	6	5

[a]Based on publications; estimated total technical personnel 110.
[b]Based on personnel; estimated total technical personnel 170.
[c]Based on personnel and dollars; estimated total technical personnel 480.
[d]Based on personnel and dollars; estimated total technical personnel 590.

new tactical concepts for their employment have never been battle tested. Furthermore seasoned combat commanders whom we seek to employ have difficulty in translating their WWII and Korean experience to incorporate these new elements, and must feel the need of new data sources as keenly as we do. The picture is made even more complicated by the fact that we must prepare for a series of little wars in remote or unexpected places.

For these reasons RAC has established, with ARPA support, a field office in SE Asia, with branches in Saigon and Bangkok, and has reestablished a field office in Germany at Seventh Army Headquarters. In addition, two of the smaller RAC divisions—Combat Developments and Support Logistics—collect most of their data in the field, and Weapons Systems is actively seeking new data sources, including antiguerrilla operations.

Special warfare and counterinsurgency do not yet appear to be receiving enough OR attention in view of their increasing importance. Much of the work is being carried out in home offices; field teams still account for a bare 20 percent of the current Army OR effort, including that supported by ARPA, but it is planned to get more men into active theaters.

Increasing numbers of competent analysts are willing to work in underdeveloped areas on real world problems for protracted periods. It is less easy to man safari-type teams for field experiments if frequent absences from home are involved.

On the other hand the troubled host to a guerrilla war is inclined to resent any inference that we may be using him as a field laboratory for scientific teams even though he may welcome military assistance. And of course many smoldering or hot areas are out of bounds to us for other reasons.

Intelligence Interpretation and Its Operational Uses

I feel there is a gap in the age-old area of army intelligence. Most of the small effort shown in Table 3 is in signal intelligence. There is no lack of hardware—in being or offered by eager salesmen. The real problem lies in techniques and methods for collecting, interpreting, and using elements of information that are fragmentary, heterogeneous, stale, false, or planted. I know of no military OR area where the need is greater or where promising effort is less. We must search for new concepts and plan new experiments to catch up with changes in equipment, weapons, and tactical concepts.

SUMMARY

To recapitulate: I have reviewed some of the trends during the past few years in US Army OR and must question whether a simple projection of current trends will match future Army requirements.

I feel that the practitioners of military OR should take a careful look at the following five areas:

(1) A proper balance between single-purpose research studies in depth vs broader-gage composite research studies by multidiscipline teams.

(2) The capabilities and limitations of present OR techniques in relation to the allocation of military resources and budgets.

(3) Improved means for analyzing military effectiveness, now the weaker element of the popular cost-effectiveness ratio. This is especially true in

Army OR where permutations and innovations in organization, tactics, weapons, and equipment currently are based more on intuition than on analysis.

(4) Renewed emphasis on empirical methods and the study of operations in the field to replenish an exhausted data bank.

(5) The nature of the future battlefield and the probable places and kinds of conflict.

In closing, I want to make one broad generalization—OR for the Army no longer is separable into tidy packages of pure Army problems. Pure Army problems are becoming too rare for that. I do not mean merely joint operations with other services or combined operations with allies. Under current trends most Army problems now are composites in which military operations are becoming inextricably entangled with social, cultural, economic, and political factors at home and abroad. We cannot ignore these factors. They are fundamental parts of the real world complex of man–machines–environment whose interactions OR seeks to study.

We must prepare to meet the challenge, and I believe we can do it.

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